High Temperature Superconductors at Pressure: Theoretical Investigation

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Abstract: - In this paper we have theoretically predicted the behaviour of high temperature superconductors under different compression. Different properties such as isothermal bulk modulus at different compressions, and pressure derivative of isothermal bulk modulus have been established by using three different equation of states (I) Brennan – Stacey EOS, (II) Birch – Murnaghan EOS, (III) Vinet – Rydberg EOS for La_2CuO_4, $La_{2-x}SrCuO_4$ high-temperature superconductors. The result shows that the first derivative of isothermal bulk modulus decreases as compression increases.

Key Words: — ***Equation of state (EOSs); High-temperature Superconductor; Isothermal Bulk modulus.***

I. INTRODUCTION

Superconductors differ from ordinary conductors such as copper, graphite, and the human body. In contrast to typical conductors, whose resistance gradually diminishes, a superconductor's critical temperature causes its resistance to plummet to zero [1]. Because a superconductor can conduct electricity without resistance at this temperature, the material would not emit any heat, sound, or other sources of energy until it reached the "critical temperature" (Tc). To become superconductive, the bulk of materials must be in an extremely low energy state. Because extra energy must be wasted in the cooling process, superconductors are neither cost effective nor energy efficient. It is now being researched how to create componds that become superconductive at high temperatures [1].

At extreme low temperature (4.2 K), mercury shows superconductive behavior for the first time. After this, people tried this experiment on different materials and reached a transition temperature (Ts) about 30 kelvin.

Manuscript revised August 10, 2023; accepted August 11, 2023. Date of publication August 13, 2023.

This paper available online at www.ijprse.com

ISSN (Online): 2582-7898; SJIF: 5.59

When the resistance of body goes to zero and there is a diamagnetic field associated with that body, this phenomenon is known as superconductivity. [2] In fact, In a classical superconductor the resistance goes to zero when the temperature becomes higher compared to the absolute zero temperature, is known as the critical temperature. In 1908, Dutch physicist Heike Onnes Kamerling start to work in the field of low temperature physics by liquifying heleium. After three years, In 1911 he found that below 4.2 kelvin temperature resistivity of mercury becomes null. Onnes was also found that the application of a magnetic field which cause a decrease in the critical temperature (Tc) [2]

At temperatures close to absolute zero, a superconductor permits current to flow through a material with no resistance. It also shows Meissner effect by which the superconducting material repels magnetic field. The expensive cost of using helium to cool the material to a critical temperature has severely restricted the use of this technique. [3]

However, in recent years, significant discoveries have been made with regards to high temperature superconductors. Superconductors are employed in practically every field, including medicine, space, telecommunications, and defence. In the current world , several of these uses are highlighted in this study along with the most excited form of superconductivity . [3]

In case of high- temperature superconductors, their properties are often better described using specialized models' isothermal equation of states that take into account their specific characteristics. These models may consider factors such as the electronic band structure, Lattice vibrations and the presence of magneic interactions. Therefore, while the isothermal equation of state can be the starting point for understanding the behavior of high temperature superconductor (HTS) materials, It is advisable to consult specialized models and experimental data that are specially developed for high temperature superconductors for a more accurate description of their properties at elevated temperatures

High temperature superconductors are a class of materials which exhibits superconductivity at relatively higher temperature compared to conventional superconductors. HTS typically have complex crystal structures and unique electronic properties. While the isothermal equation of state provides a useful description of the behaviour of many materials, including some superconductors, it may not capture the full difficulty of the high temperature superconductor materials. So, in this paper we will discuss the behaviour of some high temperature super conductor sunder the three equations of states

II. Method of Analysis

We will used three different equations of states named.,

2.1 Brenan-Stacey EOS

This expression is derived by using thermodynamics formulation for Gruneisen parameter [4,5].

$$P=3K_0x^{-4}/(3K_0-5)[\exp\{(3K_0'-5)(1-x^3)\}/3-1] \qquad (1)$$

Where $x = (V/V_0)^{1/3}$

2.2 Vinet-Rydberg EOS

This expression based on the universal relationship between binding energy and interatomic seperation for solids [6,7].

$$P=3K_0x^{-2}(1-x)\exp[n(1-x)] \qquad (2)$$

Where $x = (V/V_0)^{1/3}$ and $n= 3/2(K_0'-1)$

2.3 Birch-Murnaghan EOS

This expression is derived by using finite strain theory [8].

$$P=3/2K_0[x^{-7}–x^{-5}][1+3/4(K_0' -4)(x^{-2}-4)] \qquad (3)$$

Here, K_T is the isothermal bulk modulus which is calculated by using this formula: $K_T= - V (\partial P/ \partial V) T$

And K_T' is the first order pressure derivative of bulk modulus can be calculated by the formula: $K_T' = (\partial KT/ \partial P) T$

Now, we can calculate the value of Gruneisen Parameter (gama) by using the formula given by Bortan and Stacey [9]. In these equations, the term V is the volume at pressure P and V_0 is also volume but at zero pressure, K_0 is the isothermal bulk modulus at zero pressure and K_0 ‘ is the first derivative of isothermal bulk modulus at zero pressure [10].

III. Result and Analysis

In this paper, we have described three different equation of state such as, Brennan Stacey EOS, Vinet Rydberg EOS, Birch-Murnaghan EOS for calculating pressure, isothermal bulk modulus (K_T), and first pressure derivative of isothermal bulk modulus (K_T') at different compressions the value of pressure(P) is calculated by using equation (1)(2)(3). The results obtained in the present study will with those reported in recent studies.

Table.1. Values of input data for K_0 (Gpa) and K_0' (Gpa)

Material	K_0	K_0'	References
$Nd_{2-x}Ce_xCuO_4$	507.64	15.62	[11]

Now Plot a graph between pressure(P) and Compression (V/V_0) for high- temperature superconductor ($Nd_{2-x}Ce_xCuO_4$).

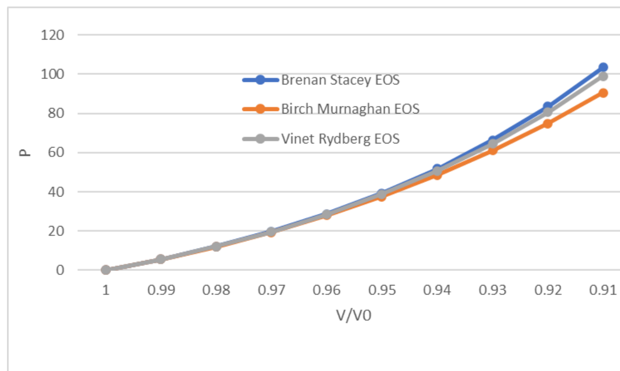

Fig.1. Pressure Vs Compression for $Nd_{2-x}Ce_xCuO_4$

From Figure. 1 it is clear that on increasing pressure(P), the value of compression(V/V0) increases for high-temperature superconductor ($Nd_{2-x}CexCuO_4$). For $Nd_{2-x}Ce_xCuO_4$, all the three EOSs corresponds well with each other upto compression range (V/V_0 = 0.95) at pressure (40Gpa) respectively then after all three EOSs start deviating with each other [11].

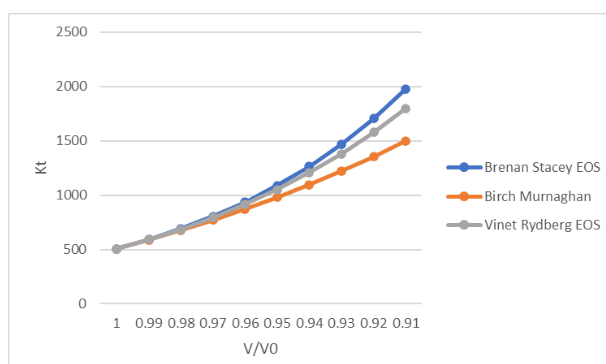

Fig.2. Isothermal Bulk modulus Vs Compression for $Nd_{2-x}Ce_xCuO_4$

Further the graph for isothermal bulk modulus versus compression for four high-temperature superconductors ($Nd_{2-x}CexCuO_4$) are shown figure.2 [12-13]. Whereas, for $Nd_{2-x}CexCuO_4$ all three EOS corresponds well upto compression range (V/V_0 = 0.96) at isothermal bulk modulus 900 Gpa respectively but all the three, the Brennan-Stacey EOS, Vinet-Rydberg EOS, and Birch-Murnaghan EOS starts deviating above the isothermal bulk modulus 900 Gpa with each other [14-15].

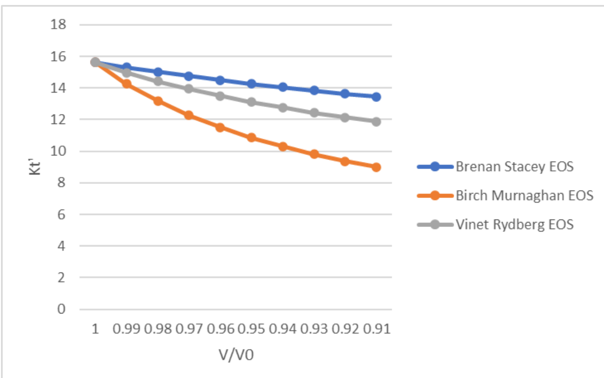

Fig.3. First derivative of Isothermal Bulk modulus Vs Compression for $Nd_{2-x}Ce_xCuO_4$

Further, 3 it is clear that on decreasing the first pressure derivative of isothermal bulk modulus, the value of compression increases for all four high-temperature superconductors [16]. Whereas for Nd2-xCexCuO4-y all three EOSs (Brennan-Stacey EOS, Birch-Murnaghan EOS, Vinet-Rydberg EOS) does not corresponds with each other in entire compression range [17-24].

IV. Conclusion

It is clear that derivative of bulk modulus is decreasing as the value of compression increases for high-temperature superconductors. Whereas, for Nd2-xCexCuO4 all three EOSs (Brennan Stacey EOS, Birch-Murnaghan EOS, Vinet-Rydberg EOS) does not corresponds with each other in entire compression range.

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